LIGHTWEIGHT COLD WEATHER UNDERWEAR INVESTIGATION

DEPARTMENT OF THE NAVY
SUPPLY SYSTEMS COMMAND

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The Navy Clothing and Textile Research Facility was tasked by the Marine Corps Systems Command to conduct testing of various types of lightweight cold weather underwear materials for physical and thermal characteristics. These tests were conducted in order to develop a Marine Corps standard for future product development. Based on test results, two fabrics were recommended as good candidates for use in lightweight cold weather underwear.

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TABLE OF CONTENTS

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LIST OF TABLES

LIGHTWEIGHT COLD WEATHER UNDERWEAR INVESTIGATION

INTRODUCTION

In August 1992, the Navy Clothing and Textile Research Facility (NCTRF) was tasked by the Marine Corps Systems Command (PM CSS), Quantico, VA, to conduct testing of various types of lightweight cold weather underwear materials for physical and thermal characteristics. These tests were conducted in order to develop a Marine Corps standard for future product development.

Tests of underwear material performance would be conducted to determine wet and dry insulation values, moisture retention, moisture transport, vapor transmission, durability and launderability. These tests would be based on standard testing procedures common in the commercial marketplace and certified by the American Society for Testing Materials (ASTM). If no ASTM test method is in existence, industry accepted practices will be utilized.

Seven lightweight candidate fabrics were supplied by the Marine Corps for testing. Since no commercial test method could be found for wicking, an absorbency test was modified that is used on terry knit towels.

A review of the test results shows that it was difficult to predict the best lightweight fabric without thermal manikin testing on prototype clothing. However, analysis of the fabric testing data suggested that the fabrics obtained from Milliken (B) and Patagonia (C) both performed well and would be excellent candidates for lightweight cold weather underwear.

BACKGROUND

The current cold weather underwear garments used by the Marine Corps are made from texturized or non-texturized multifilament polypropylene, as specified in material specification MIL-C-44161. The cloth is a circular or warp knit terry loop material. The Marine Corps requested a laboratory evaluation of knit materials be conducted that are used for underwear garments in the civilian marketplace. In addition to polypropylene, these materials included polyester and a 50/50 polyester/wool cloth. All materials were knits. Standard physical and thermal tests were used to evaluate the candidate fabrics. However, a special wicking test had to be developed to supplement these standard tests.

MATERIAL DESCRIPTION

The candidate fabrics consisted of the following materials:

Fabric A - Thermax, a product from Dupont; 4.8 oz./yd^2; 100% polyester; rib knit; color blue.

Fabric B - Interlock, a product from Milliken; 4.8 oz./yd^2; 100% polyester; interlock knit; color pink.

Fabric C - Capilene, a product from Patagonia; 4.6 oz./yd^2; 100% polyester with a microbial finish; rib knit; color light blue.

Fabric D - As supplied by the manufacturer, this fabric was too heavy to be considered, and was not tested. The manufacturer sent a replacement material for the evaluation, and this was coded Fabric I.

Fabric E - Fabric E was never received from the manufacturer.

Fabric F - Polypropylene, a product from Coville; 5.1 oz./yd^2; 100% spun polypropylene; interlock knit; color white.

Fabric G - Thermastat, a product from Dupont; 5.4 oz./yd^2; 100% polyester; rib knit; color blue.

Fabric H - Thermax bi-ply, a product from Dupont; 6.5 oz./yd^2; 50/50 polyester/wool; jersey knit; color khaki.

Fabric I - Akwatek, a product from Wickers; 4.2 oz./yd^2; 100% polyester; rib knit; color blue.

A full description of the candidate fabrics can be found in Table I.

TABLE - I

CANDIDATE FABRICS FOR LIGHTWEIGHT COLD WEATHER UNDERWEAR

FABRIC	MANUFACTURER	NAME	MFG. CLOTH ID	STYLE #	COLOR
A	Dupont	Thermax	310	310	blue
B	Milliken	Interlock	PAT 351/ Finish 827	441284	pink
C	Patagonia	Capilene	none	441224	light blue
D	Wickers	Akwatek	1236-S	AKA 1236	dark blue
E	Celanese	BTU	none	none	
F	Coville	Poly-propylene	none	3085	white
G	Dupont	Thermastat	760	519	blue
H	Dupont	Thermax bi-ply	510	510	khaki
I	Wickers	Akwatek	5606-S	none	blue

TEST PROCEDURES

All of the candidate fabrics were subjected to standard physical and thermal tests. With the exception of the wicking test, the physical test methods that were performed on the candidate fabrics are listed in Table II. Since no commercial test methods could be found for wicking, an absorbency test was modified that is used on terry knit towels.

Physical Characteristics

The physical characteristics (air permeability, burst strength, thickness, etc.) were obtained by testing the candidate materials in accordance with the test methods listed in Table II.

Air Permeability

Air permeability testing was performed using the 16 mm orifice.

Burst Strength

Burst strength was conducted, initially, after 15 cycles of home laundering, and after 15 cycles of shipboard laundering.

Thickness

Thickness was determined using the $1.129 \pm .001$ inch presser foot with a total load of $0.6 \pm .03$ psi.

Non-Fibrous Content

Non-fibrous content was conducted for the measure of starch and protein content, including chloroform-soluble and water-soluble material on the finished materials.

Water Repellency

Water repellency testing was conducted using dynamic and static absorption to measure the resistance to wetting of the fibers and yarns in the fabric.

Dimensional Stability

The dimensional stability for all of the candidate fabrics was determined using the test methods listed in Table II. Testing was conducted at a wash temperature of $140^{o}F$, $105^{o}F$ rinse using the normal cycle, and tumbled dry in a commercially available home washer and drier. Measurements were taken after the first, fifth, and fifteenth laundering and drying cycle.

Laundering Durability was also determined after shipboard laundering (Formula II - $140^{o}F$). Measurements were taken after the first, fifth, and fifteenth laundering and drying cycle.

TABLE - II

LABORATORY TEST METHODS

Characteristics	Test Method*
Fabric Count (Wales and Courses)	D3887 ASTM**
Weight	D3776, Option C, ASTM
Air Permeability	D737 ASTM
Burst Strength	D3787 ASTM
Thickness	D1777 ASTM
pH	TM 2811
Non-Fibrous Content	TM 2611
Water Absorption (Dynamic)	AATCC-70 (1988)***
Water Absorption (Static)	AATCC-21 (1983)
Dimensional Stability	AATCC-135 (1987) (1)Vai
Laundering Durability	Shipboard Formula II
Pilling Resistance (Brush)	D3511 ASTM
Elongation (Apparent) at Break	D5034 ASTM
Stretch Properties of Knitted Fabrics	D2594 ASTM

* Federal Standard for Textile Test Methods No. 191A, except where noted

** ASTM - American Society for Testing and Materials

*** AATCC - American Association of Textile Chemists and Colorists

Pilling Resistance

Pilling resistance was conducted as specified in the test method. Evaluation was performed subjectively in conjunction with the standard pilling chart for knitted fabrics.

Elongation (Apparent) at Break

Elongation (Apparent) at Break was performed with no pre-tensioning, using 2x1 inch jaws on an Instron with a three inch gauge length operating at 12 inches per minute.

Stretch Properties

Stretch properties evaluation of the knits was performed for both fabric growth and stretch as specified in the test method for form-fitting (semi-support) knitted materials.

Wicking Test

Since no commercial test methods could be found for wicking, an absorbency test was modified that is used on terry knit towels. The test consisted of the following procedure: Samples of one inch wide by six inches long were cut from both the wale and course direction of the cloth. The specimens were suspended vertically so that approximately 3 centimeters (cm) was immersed in a dye solution of Acid Red 151 (Merpacyl Red L, Color Index No. #474175 of the Buyers Guide of the American Association of Textile Chemists and Colorists) and distilled water. The dye solution was of sufficient intensity to allow ready identification of the water level and rise of the solution in the fabric. Small weights were fastened to the specimen to keep it immersed throughout the test. The measurement of the rise of the solution was made from the level of the liquid. The rate of absorbency was measured as the distance traversed by the liquid in the specimen during the five minute test period. The time was recorded the instant the specimen end contacted with the solution. The rate of absorbency of the sample unit was the average of the results obtained from the five specimens in each of the wale and course directions. These data were reported separately to the nearest 0.1 cm. This method worked well for those test specimens that were light in color. However, the darker materials were difficult to measure, because the high point of the water level on the test specimens was masked by the color of the fabric.

Thermal Characteristics

Guarded Hot Plate Testing Before And After Laundering

Guarded Hot Plate testing was conducted according to NCTRF Project 93-2-91 Task Statement of FY93 to determine thermal insulation (clo) and water vapor permeability (i_m) values. These were run before and after laundering with lightweight underwear materials.

Methods And Procedures

Testing was conducted on the fabrics, before and after laundering, using the guarded hot plate chamber located at Building #7. Testing was conducted on three separate samples of the materials. Total clo for each material was determined using ASTM Method D-1518. Since there are no applicable standards for i_m testing, the standards set forth in ASTM Method D-1518, except for ambient temperature, were used. To measure i_m, an ambient temperature of 27°C was used, 7°C greater than allowed for the measurement of clo. This was done because of the higher power requirements due to the evaporation of moisture from the guarded hot plate test surface. Conditions for clo and i_m determinations were as follows:

clo:	Ambient temperature	= 20°C
	Dewpoint temperature	= 10°C
	Relative Humidity	= 50%
	Plate temperature	= 34°C
i_m:	Ambient temperature	= 27°C
	Dewpoint temperature	= 15°C
	Relative Humidity	= 48%
	Plate temperature	= 34°C

Statistics

A statistical analysis was performed on both the clo and i_m/clo ratio data. These are the data that were used to screen for differences between the candidate materials. Clo was examined because the higher the clo values, the greater the thermal insulation, and, as a result, the warmer the material would be for the wearer. Also, the higher the i_m/clo ratio, the greater the overall rate of heat loss through the material. As a result, the material will be less stressful under heat stress conditions. A two factor (candidate material x wash status) analysis of variance was utilized. A p value of 0.05 was used for significance. Tukey's test was used to determine the critical difference between both the materials and the effect of laundering.

RESULTS AND DISCUSSION

Physical Properties

The test data are summarized in Table III.

Fabrics A, B, C, G and I were constructed from 100% polyester fibers. Fabric F was constructed from 100% polypropylene. Fabric H is a 50% polyester/50% wool blend (two ply material). The bi-ply material (Fabric H) was included in the test, even though this fabric fell outside the specified weight range of 4.0-5.0 oz./yd^2. In addition, Fabrics F and G were slightly heavier than the 5.0 oz./yd^2 specified by the program manager at the Marine Corps.

Fabric I had the highest air permeability, while material F was the lowest. Overall, all materials were comparable in this test parameter.

The bi-ply fabric (Fabric H) had the highest burst strength initially, and all materials, except for Fabrics A and G, exhibited a slight increase in burst strength after fifteen launderings (both home and shipboard methods).

All fabrics exhibited a pH which is normally specified for fabrics (ranged from 5.4 to 8.4).

Non-fibrous content was greatest on Fabrics A and F, with results averaging 3.0% or greater.

Dynamic water absorption was greatest on Fabric A and the lowest on Fabric I. The static water absorption test did not show any significant difference between materials, with results ranging between 20% and 30% pickup.

Dimensional stability, determined by the home laundering method, yielded varying shrinkage and elongation values, but Fabrics B and C appeared to be the best performers. For informational purposes, a positive value denotes shrinkage, and a negative value, enclosed in parentheses, denotes elongation. The shrinkage or elongation grew progressively worse with repeated launderings and dryings. The same holds true for laundering by the Shipboard Formula II method.

Elongation for knits yielded typical results for rib type materials, with the course direction having the greatest extensibility.

Fabric growth was also greatest in the course direction when measured after sixty seconds and sixty minutes of relaxation. The stretch properties of all the knit underwear were greatest in the course direction.

Fabric C exhibited the best wicking (absorbency) results in both the wale and course direction. As stated above, problems existed with gauging the end point of the test on some fabrics (especially A, D and I) due to the dark color of the fabric.

Thermal Properties

The lightweight underwear can be worn in both a cold and a heat stress environment. In the cold, if the wearer is not active, the underwear need only provide thermal insulation. However, if the wearer is active and is exerting him/her self, the underwear must provide an additional function and allow the escape of body heat.

To reduce cold stress, thermal insulation is required in order to reduce the loss of body heat. The more insulation worn, the slower the rate of heat loss. Therefore, if protection from the cold is the major concern, the material that provides the greatest amount of thermal insulation (clo) is needed. The material with the highest thermal insulation value is the best choice to reduce cold stress.

TABLE - III

SUMMARY OF TEST RESULTS OF SEVEN CANDIDATE FABRICS

Test	Fabric A	Fabric B	Fabric C	Fabric F	Fabric G	Fabric H	Fabric I
Weight (oz./yd^2)	4.8	4.8	4.6	5.1	5.4	6.5	4.2
Fiber Type	polyester	polyester	polyester	poly-propylene	polyester	polyester wool	polyester
Knit Type	rib	interlock	rib	interlock	rib	jersey	rib
Fabric Count (W/C)	32/32	26/25	46/35	29/22	38/28	24/29	42/32
Air Permeability ($ft^3/min/ft^2$)	547.0	455.0	587.0	384.0	468.0	404.0	622.0
Burst Strength (lbs)							
Initial	88	111	94	140	94	159	77
Home (15x)	95	117	105	150	88	169	82
Shipboard (15x)	86	113	101	158	95	167	85
Thickness (in.)	.027	.020	.024	.028	.027	.033	.022
pH	7.6	8.2	7.4	7.4	8.4	5.4	7.5
Non-Fibrous Content (%)	3.4	1.0	1.0	3.0	1.7	1.8	1.6
Water Absorption (%)							
Dynamic	40.5	28.1	28.9	34.3	36.5	36.3	27.9
Static	22.5	20.6	25.4	25.6	22.4	29.8	21.7

TABLE - III (Cont'd)

SUMMARY OF TEST RESULTS OF SEVEN CANDIDATE FABRICS

Test	Fabric A	Fabric B	Fabric C	Fabric F	Fabric G	Fabric H	Fabric I
Shrinkage (%) (Home)							
1x (W/C)	0.3/9.8	2.1/2.7	3.4/3.7	10.0/(-1.0)	4.2/(-0.9)	8.9/7.3	6.4/(-1.9)
5x (W/C)	3.6/8.6	2.5/3.3	4.4/2.7	13.6/(-2.9)	6.4/0.8	9.8/8.3	6.9/(-4.5)
15x (W/C)	3.0/14.1	4.4/5.6	5.1/4.3	16.1/(-0.2)	7.3/2.2	10.7/8.9	7.5/(-1.4)
Shrinkage (%) (Shipboard)							
1x (W/C)	1.8/13.6	2.9/3.2	3.7/1.0	13.8/(-2.4)	7.6/0.7	10.3/9.8	6.2/(-3.1)
5x (W/C)	10.3/12.2	3.9/3.8	6.0/2.1	18.3/(-2.0)	10.5/(-7.0)	12.0/8.8	8.5/(-2.8)
15x (W/C)	4.3/10.2	5.8/4.8	7.6/1.2	22.1/(-1.4)	11.8/(-10.1)	11.8/9.3	10.4/(-6.1)
Pilling	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Elongation (%) (W/C)	71/256	49/159	53/213	70/297	72/273	108/215	55/196
Growth (%) (W/C)							
after 60 seconds	12.0/20.3	7.3/9.0	7.3/14.7	19.7/39.3	8.3/22.3	10.3/12.7	9.0/20.3
after 60 minutes	10.0/16.7	6.7/7.0	6.7/13.3	12.3/30.0	8.0/20.0	9.0/10.3	7.7/20.0
Stretch (%) (W/C)	8.0/31.0	3.0/6.5	4.5/18.5	6.0/30.5	7.5/19.5	8.5/23.5	6.0/11.0
Wicking (cm) (W/C)	0.9/0.4	8.6/7.7	10.0/8.5	6.0/4.9	5.3/4.5	5.4/5.6	6.4/6.2

(W/C) denotes wale and course direction.

Heat stress can also be a limiting factor when wearing cold weather protective garments. The wearer can become sweat wetted during exertion and will then experience an after chill once exertion has stopped. To reduce this after chill, materials are needed that will allow body heat to escape, and as a result, reduce heat stress. To help make this choice, the i_m over clo ratio (i_m/clo) was calculated. This ratio indicates the amount of overall heat loss through the materials. The higher the i_m/clo ratio, the greater the rate of heat loss through the material. As a result of the increased heat losses, the less stressful the material is to the wearer.

The test data for clo, i_m and i_m/clo before and after laundering are summarized in Table IV. The bare plate value for all clo determinations was 0.41 clo. Both clo and i_m values were reported as total values (the values included the air layer). The values were the average of three independent measures.

clo:

Before Laundering

Table V lists the rank order of the materials before and after laundering, based on thermal insulation (clo). There were statistically significant differences in clo values between materials. Prior to laundering, Fabrics A, F, H, I and G provided the greatest thermal insulation and are statistically equivalent.

After Laundering

There were significant differences between candidate materials after laundering. Sample H provided significantly more thermal insulation than the rest of the materials. Samples A, F and H were the top three choices before laundering and after laundering.

i_m/clo Ratio:

Before Laundering

Table VI shows the rank order of the materials before and after laundering, based on the i_m/clo ratios. There were statistically significant differences for some of the materials. Samples C, B, G and F yielded the highest i_m/clo ratios and are statistically equivalent.

After Laundering

There were significant differences in the i_m/clo ratio between the materials after laundering. Samples B, C, I, and G yielded the highest ratios and are statistically equivalent. Sample H resulted in the lowest i_m/clo ratio both before and after laundering. Samples B, C and G were in the top three before and the top four after laundering.

TABLE - IV

GUARDED SWEATING HOT PLATE AVERAGED RESULTS
BEFORE AND AFTER LAUNDERING

Materials	clo*		i_m**		i_m/clo***	
	Before	After	Before	After	Before	After
Fabric A	0.71	0.79	0.51	0.51	0.72	0.64
Fabric B	0.64	0.71	0.51	0.49	0.80	0.70
Fabric C	0.65	0.70	0.52	0.48	0.80	0.69
Fabric F	0.72	0.78	0.55	0.48	0.77	0.61
Fabric G	0.68	0.72	0.53	0.47	0.78	0.66
Fabric H	0.71	0.86	0.49	0.47	0.69	0.54
Fabric I	0.70	0.70	0.52	0.48	0.74	0.68

* clo = total thermal insulation
** i_m = water vapor permeability
*** i_m/clo = indicates the amount of evaporative heat loss per unit of thermal insulation; the higher the i_m/clo ratio, the greater the overall rate of heat loss through the material

TABLE - V

CLO RANK ORDER BEFORE AND AFTER LAUNDERING

Fabric	clo Before	Fabric	clo After
F	0.72	H	0.86
A	0.71	A	0.79
H	0.71	F	0.78
I	0.70	G	0.72
G	0.68	B	0.71
C	0.65	C	0.70
B	0.64	I	0.70

Bars located to the right of the fabrics indicate statistical equality.

TABLE - VI

I_M/CLO RATIO RANK ORDER BEFORE AND AFTER LAUNDERING

Fabric	i_m/clo Before	Fabric	i_m/clo After
C	0.80	B	0.70
B	0.80	C	0.69
G	0.78	I	0.68
F	0.77	G	0.66
I	0.74	A	0.64
A	0.72	F	0.61
H	0.69	H	0.54

Bars located to the right of the fabrics indicate statistical equality.

The Effect of Laundering

clo:

Laundering increased the thermal insulation (clo) of most materials. Sample H resulted in the greatest increase in clo due to laundering, 0.15 clo. The average increase in clo due to laundering was 0.08 clo, and is statistically significant. Sample I was not affected by laundering.

i_m/clo:

Laundering reduced the i_m/clo ratio of the materials. The average reduction in the i_m/clo ratio due to laundering was 0.11 and is statistically significant.

CONCLUSIONS

Based on Physical Testing

Based on the review of test results, the fabric with the best performance characteristics is difficult to identify. But in comparative analysis, Fabric B (from Milliken) and Fabric C (from Patagonia) both performed well in dimensional stability after repeated launderings at high wash temperatures. Fabric B also had the best overall recovery after stretch and low growth. The negative aspect of B includes a high pH, which is within specified norms, but may be a concern due to contact with skin, because the underwear is a form-fitted garment. Fabric C had the best results for the wicking evaluation. Fabric H (from Dupont) had the highest burst strength results initially and after laundering, but was also the heaviest fabric due to its two-ply construction, and had shrinkage values greater than ten percent.

Based on Thermal Testing

Laundering yielded an increase in the thermal insulation of the materials. This will have a positive effect for protection in the cold, since the greater the thermal insulation, the slower the rate of heat loss from the body of the wearer.

Laundering decreased the i_m/clo ratio of the materials. This will have a negative effect for the reduction of heat stress, since the lower the i_m/clo ratio, the less overall heat loss through the materials. Fabrics B, C and G are in the top four, both before and after laundering.

RECOMMENDATIONS

Fabrics B and C are good candidates for lightweight cold weather underwear materials, based on physical and thermal laboratory data.

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